

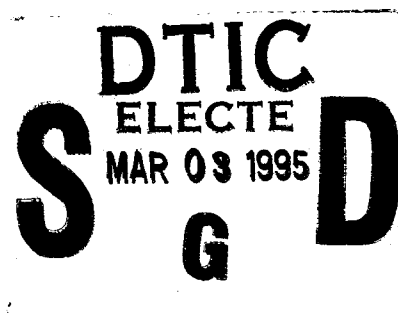
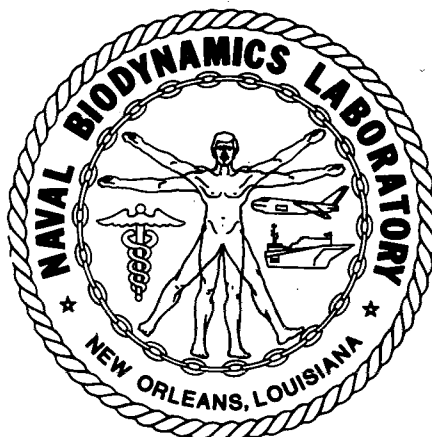
DYNAMIC RESPONSE OF THE HYBRID III DUMMY TO +G_z SIMULATED SHIP SHOCK -- CUSHIONED VS HARD SEATS

G. C. WILLEMS, W. H. MUZZY, III, D. KNOUSE, and F. GILREATH

Research Report

November 1991

NAVAL BIODYNAMICS LABORATORY
BOX 29407
New Orleans, LA 70189-0407



19950227 073

Approved for public release; distribution is unlimited.

Prepared for

Naval Medical Research and Development Command
Bethesda, MD 20889-5044

DTIC QUALITY INSPECTED

Approved by



Thomas G. Dobie, M.D.
Chairman, Scientific Review Committee

Released by



CAPT Douglas W. Call, MSC, USN
Commanding Officer

Naval Biodynamics Laboratory
P. O. Box 29407
New Orleans, LA 70189-0407

Approved for public release; distribution is unlimited. Reproduction in whole or part is permitted for any purpose of the United States Government.

The interpretations and opinions in this work are the authors' and do not necessarily reflect the policy and views of the Navy or other government agencies.

In the interest of precision, trade names of products are cited. These citations do not constitute endorsements of the products.

TABLE OF CONTENTS

1. INTRODUCTION	1
2. METHODS	3
2.1 TEST ITEM	3
2.2 INSTRUMENTATION	4
2.3 TEST FIXTURE	4
2.4 SEATS	6
3. RESULTS	6
3.1 REPEATABILITY	9
3.2 HARD SEAT COMPARISON	10
3.3 MANIKIN RESPONSE	20
4. SUMMARY	20
5. CONCLUDING REMARKS	21
REFERENCES	A-1
APPENDIX A	

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input checked="" type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

LIST OF FIGURES

Figure 1.	Comparisons of Shock Forces Measured on Vertical Accelerator (top) and USS YORKTOWN (CG-48)	2
Figure 2.	Coordinate System Definition	4
Figure 3.	SPOC on Vertical Accelerator	5
Figure 4.	Hard Seat #1	6
Figure 5.	Hard Seat #2	6
Figure 6.	Soft Seat Repeatability, Z-axis, 10 G Nominal	7
Figure 7.	Soft Seat Repeatability, Z-axis 25 G Nominal	7
Figure 8.	Hard Seat Repeatability, Z-axis 10 G Nominal	8
Figure 9.	Hard Seat Repeatability, Z-axis, 25 G Nominal	8
Figure 10.	Hard Seat Pelvis X Comparison, Nominal Z Input at Chair	9
Figure 11.	Hard Seat Pelvis Z Comparison, Nominal Z Input at Chair	10
Figure 12.	Shock Propagation through Pelvis and T-1 SPOC	11
Figure 13.	Shock Propagation through Pelvis and T-1 Hard Seat	12
Figure 14.	Hard vs. Soft Seat Comparison, Z-axis, 10 G Nominal	13
Figure 15.	Hard vs. Soft Seat Comparison, Z-axis, 25 G Nominal	13
Figure 16.	Head @Y Angular Acceleration, Peak to Peak Values	14
Figure 17.	Head X Linear Acceleration, Peak to Peak Values	14
Figure 18.	Comparison of Actual and Simulated Shock Pulses	16
Figure 19.	Pelvis Z-axis Response to Actual and Simulated Shock Pulses	17
Figure 20.	T-1 Z-axis to Actual and Simulated Shock Pulses	18
Figure 21.	Head Z-axis Response to Actual and Simulated Shock Pulses	19

Hybrid III Dummy Response to +G_z Simulated Ship Shock

1. INTRODUCTION

Shock trials conducted by the Naval Sea Systems Command (NAVSEASYS COM) represent continuing efforts toward improving ship performance and survivability in combat. The crew onboard a ship at-sea which is undergoing shock trials brace themselves for the upcoming shock by assuming a standard crouched position with bent knees. Since this defensive posture is not representative of a real-life situation, the question arose as to the possibility of deleterious effects of shock on crewmembers while seated at their duty stations performing normal tasks and unaware of any upcoming shock forces.

To obtain insight into the potential for shock forces which may injure unaware crewmembers, NAVSEASYS COM tasked the Naval Biodynamics Laboratory (NAVBIODYNLAB) with measuring dynamic response to ship shock on an instrumented anthropomorphic manikin. The manikin was seated in a Special Purpose Operator's Chair (SPOC) which was located in the Combat Information Center (CIC) onboard the heavy cruiser, USS MOBILE BAY (CG-53). Subsequently, NAVBIODYNLAB also participated in the shock trials onboard a Nimitz class aircraft carrier, the USS ROOSEVELT (CVN-71). The manikin was deployed in a standing position during this operation.

Prior to transferring the equipment to the ships, the Laboratory conducted a series of in-house simulated shock tests in the vertical (+G_z) direction. The vertical accelerator was used as the experimental shock-imparting device and previous USS YORKTOWN (CG-48) cruiser shock trial data was used as the template. The purpose of these tests was to verify the ability of the instrumentation and data acquisition hardware to operate under severe shock conditions. The goal was successfully accomplished and demonstrated that the vertical accelerator is indeed capable of reproducing the vertical component of shock forces measured during actual shock trials (Figure 1). This capability suggested a variety of valuable experiments concerning human response to ship shock performed in a simulated environment. This report documents one such experiment.

This Command, since 1971, has performed related research in the area of human dynamic response to various impact stimuli and has developed instrumentation, data acquisition and data analysis techniques directly applicable to the subject task. NAVBIODYNLAB research has utilized instrumented manikins, human volunteers and non-human primates.

NAVAL BIODYNAMICS LABORATORY REPORT

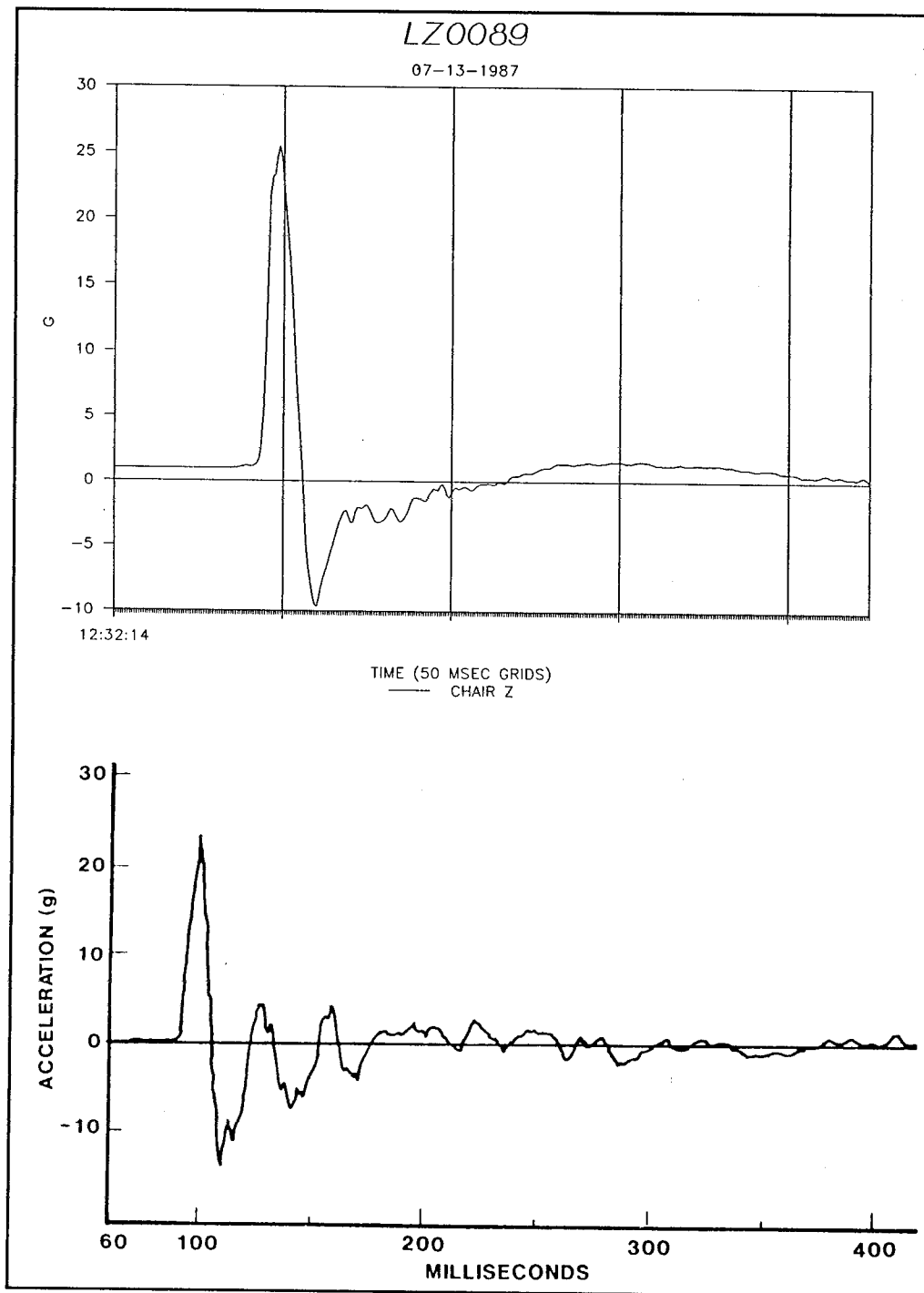


Figure 1. Comparisons of Shock Forces Measured on Vertical Accelerator (top) and USS YORKTOWN (CG-48).

2. METHODS

2.1 TEST ITEM

A fiftieth percentile Hybrid III manikin was selected for this project. The Hybrid III is the most advanced available test device in terms of biofidelity, and is representative of the weight and general body structure of a healthy male in the general population. This manikin is the Federal Government's standard test article for evaluating automotive restraint systems.

2.2 INSTRUMENTATION

The Hybrid III manikin's shock input and resultant dynamic response were measured using four accelerometer clusters. To provide greater clarity and understanding of the manikin response to the shock tests, it is necessary to describe the nomenclatures, placements and axes orientation of the transducers as mounted on the chair pedestal and in the manikin. Figure 2 depicts the manikin and indicates the transducer locations and alignments. Transducers labeled as X, Y, and Z were linear accelerometers, while those labeled AX, AY, and AZ were angular accelerometers. Packages containing three accelerometers each were installed in the head and first thoracic vertebrae (T-1) area, and aligned to the X, Y, and Z coordinate system shown in Figure 2. A package containing two accelerometers was installed in the pelvis and similarly aligned with the local coordinate system. Three angular accelerometers were also installed in the head and oriented such as to measure angular accelerations about the previously defined head coordinate system. This additional head instrumentation was deemed necessary, since substantial head rotation has been observed in prior human research involving inputs similar to those expected in the ship shock trials, and is thought to be a significant head injury parameter.

The specific transducer packages used for the experiments were:

- ▶ Chair X, Y, and Z: Endevco Model 2262-25 linear accelerometers.
- ▶ Pelvis X and Z: Endevco Model 2262-25 linear accelerometers.
- ▶ T-1 X, Y and Z: Entran Model EGA-50D linear accelerometers.
- ▶ Head X, Y, and Z: Entran Model EGA-50D linear accelerometers.
- ▶ Head AX, AY, and AZ: Endevco Model 7302B angular accelerometers.

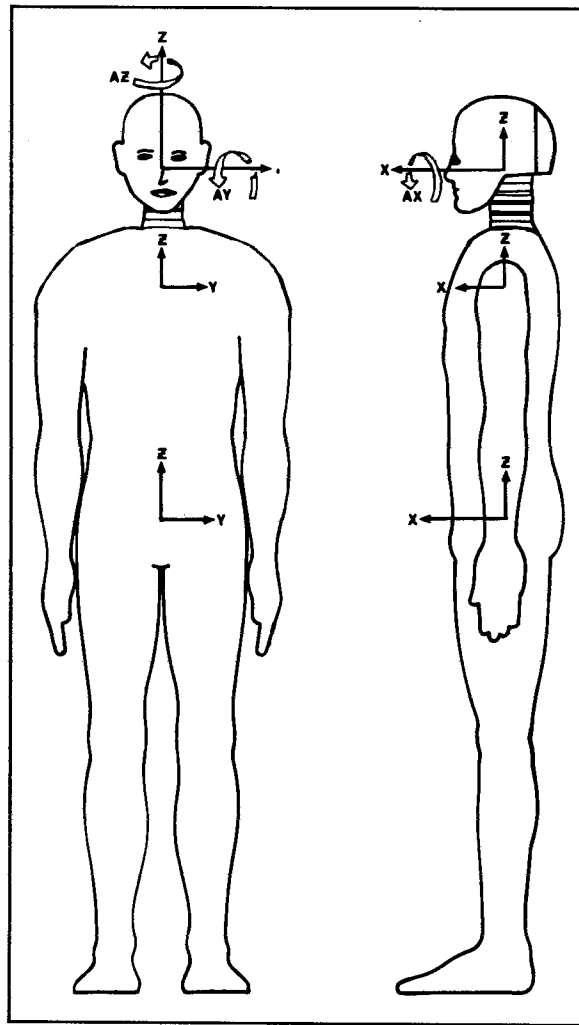


Figure 2. Coordinate System Definition.

2.3 TEST FIXTURE

The device used to impart the shock forces was NAVBIODYNLAB's Vertical Accelerator, a 6-inch diameter pneumatically powered linear accelerator capable of 40,000 pounds of thrust. It propels a carriage capable of carrying a payload in excess of 500 pounds upwards, along a 40-ft long tower-supported rail system.

2.4 SEATS

Figure 3 depicts the seat-manikin configuration utilizing the Special Purpose Operator's chair (SPOC) in the firing position on the Vertical Accelerator. The two hard-bottomed seats used in subject experiments are shown in Figures 4 and 5, respectively. The reason for using two hard seats will be discussed quantitatively in the RESULTS section. Qualitatively, the reason is as follows: the seat shown in Figure 4 (hard seat #1) consists of a steel-frame base,

Hybrid III Dummy Response to +G_z Simulated Ship Shock

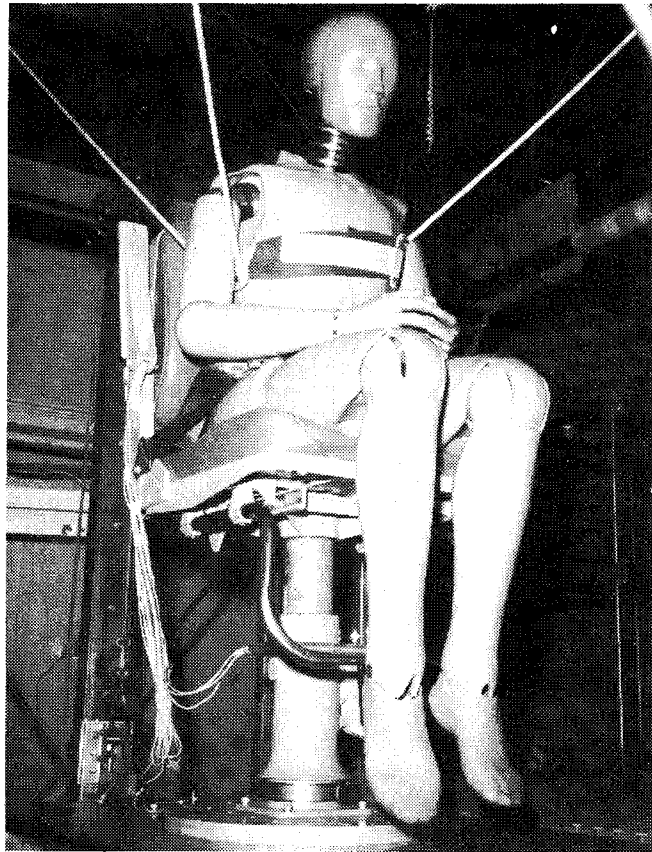


Figure 3. SPOC on Vertical Accelerator.

a wooden spacer sandwiched between two 0.75 inch aluminum plates, and a conformed molded fiberglass seat. This seat has been used at NAVBIODYNLAB for many years for a variety of experiments, including low level shock. It was speculated that the conformed "saddle" shape of the seat might introduce a significant forward motion to the manikin. This was confirmed by the initial experiments. The seat was modified to the configuration shown in Figure 5 (hard seat #2), in which the conformed fiberglass insert was replaced by a flat plate parallel to the accelerator carriage, and therefore, more likely to impart a purely vertical input to the manikin, similar to that of the SPOC.

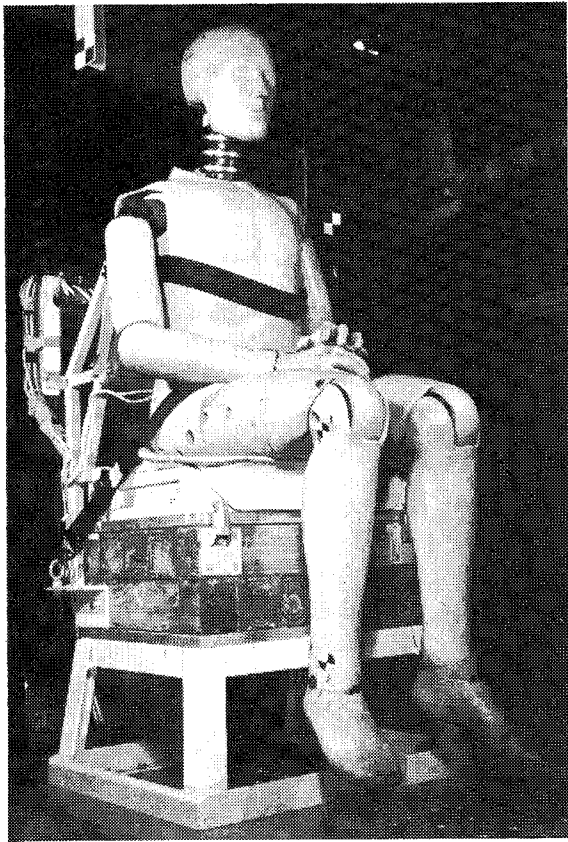


Figure 4. Hard Seat #1.

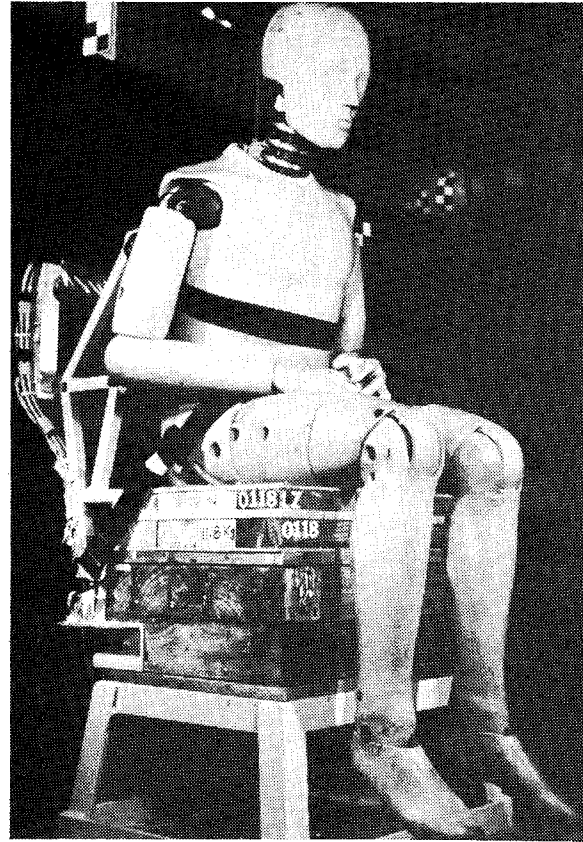


Figure 5. Hard Seat #2.

3. RESULTS

3.1 REPEATABILITY

To verify the ability of the Vertical Accelerator and the manikin-seat combinations to deliver reliable results, two tests at 10 Gs and two at 25 Gs were conducted. The shock propagation through the manikin was measured. The tests were conducted with the SPOC and hard seat #1. The results for the SPOC are shown in Figures 6 (10 Gs) and Figure 7 (25 Gs). It is obvious that repeatability is excellent at all measurement stations. Similar results were obtained for the hard seat configuration, as shown in Figure 8 (10 Gs) and Figure 9 (25 Gs). The only response with somewhat degraded repeatability is the pelvis at 10 Gs input. However, since this did not carry over to the 25 G condition, it can only be considered anomalous, inasmuch as all other responses exhibit good fidelity.

Hybrid III Dummy Response to +G_Z Simulated Ship Shock

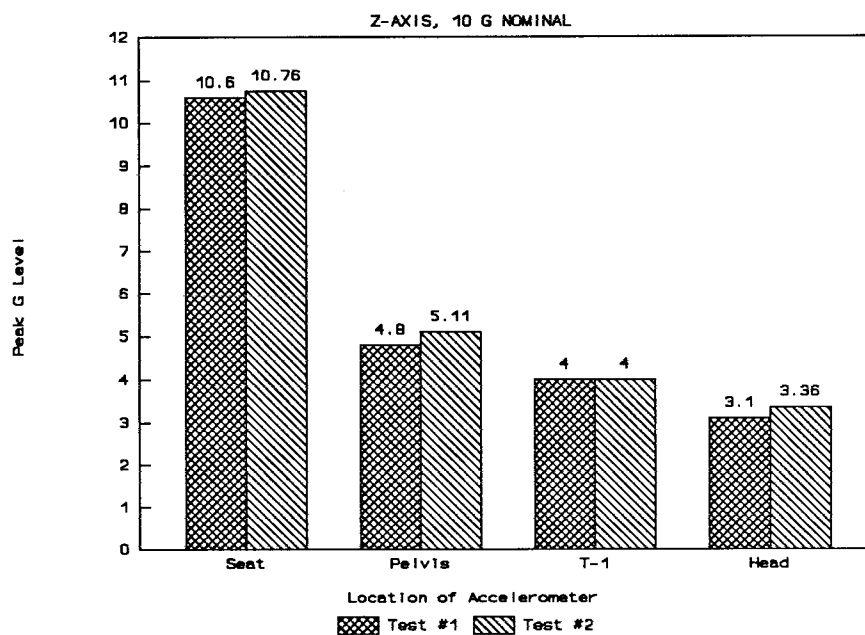


Figure 6. Soft Seat Repeatability.

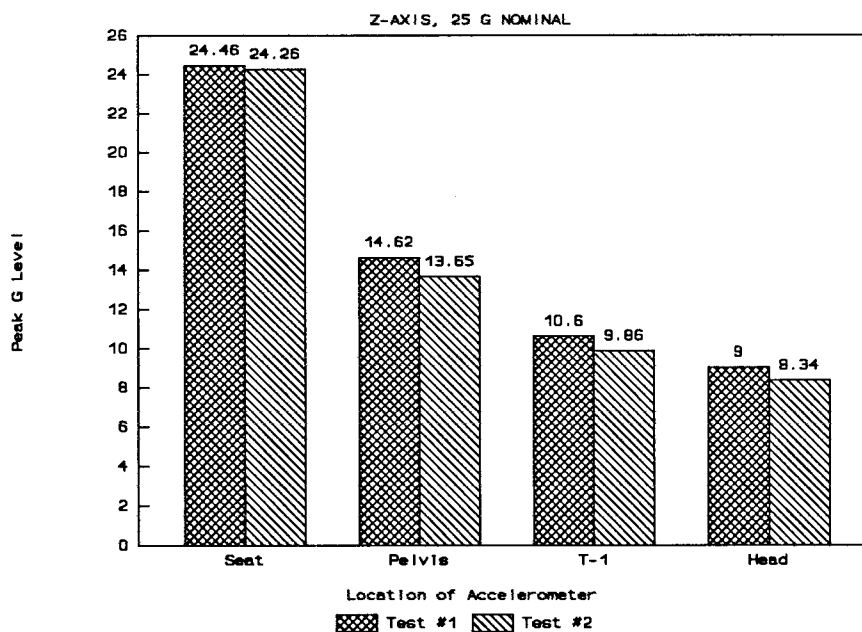


Figure 7. Soft Seat Repeatability.

NAVAL BIODYNAMICS LABORATORY REPORT

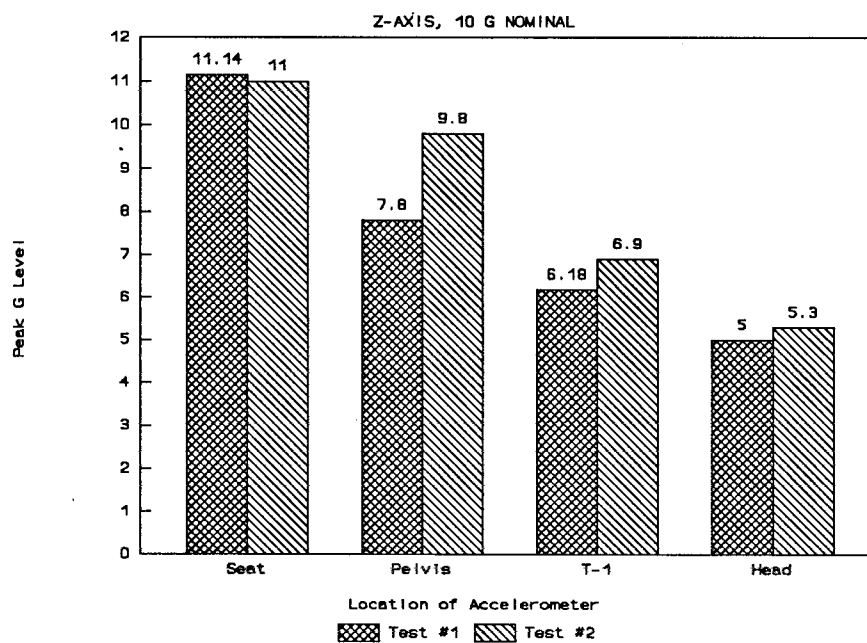


Figure 8. Hard Seat Repeatability.

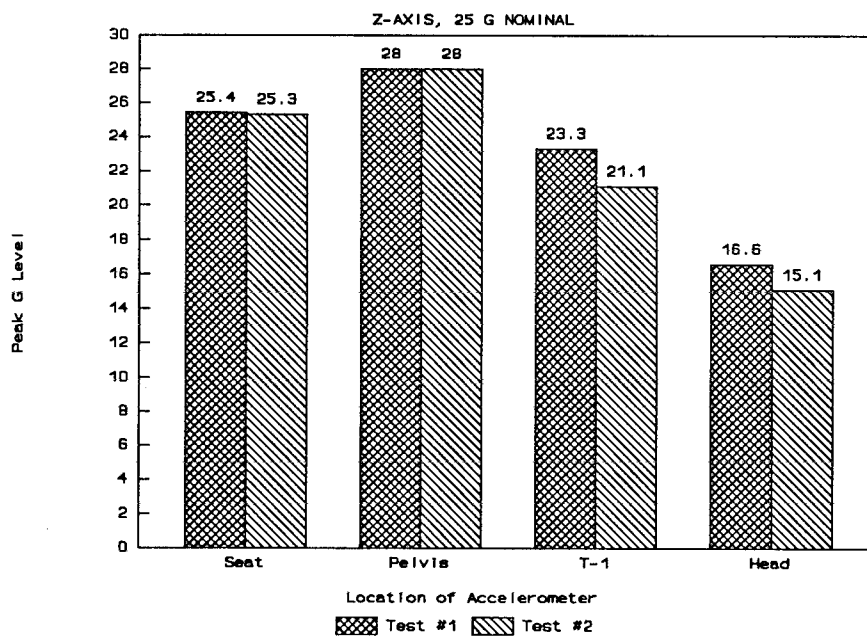


Figure 9. Hard Seat Repeatability.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

3.2 HARD SEAT COMPARISON

Due to its shape, the comformal hard seat was suspected of introducing a significant X component of acceleration. Figures 10 and 11 show the X and Z components of acceleration at the pelvis for both hard seat configurations. It is evident that the difference in response is significant at the higher acceleration levels. It is obvious from the response of the modified seat that the X input component is greatly reduced. Not unexpectedly, since the X component was reduced by the redesign, the pelvis Z component of the modified seat is larger. The remaining comparison data presented are for the SPOC and hard seat #2 only.

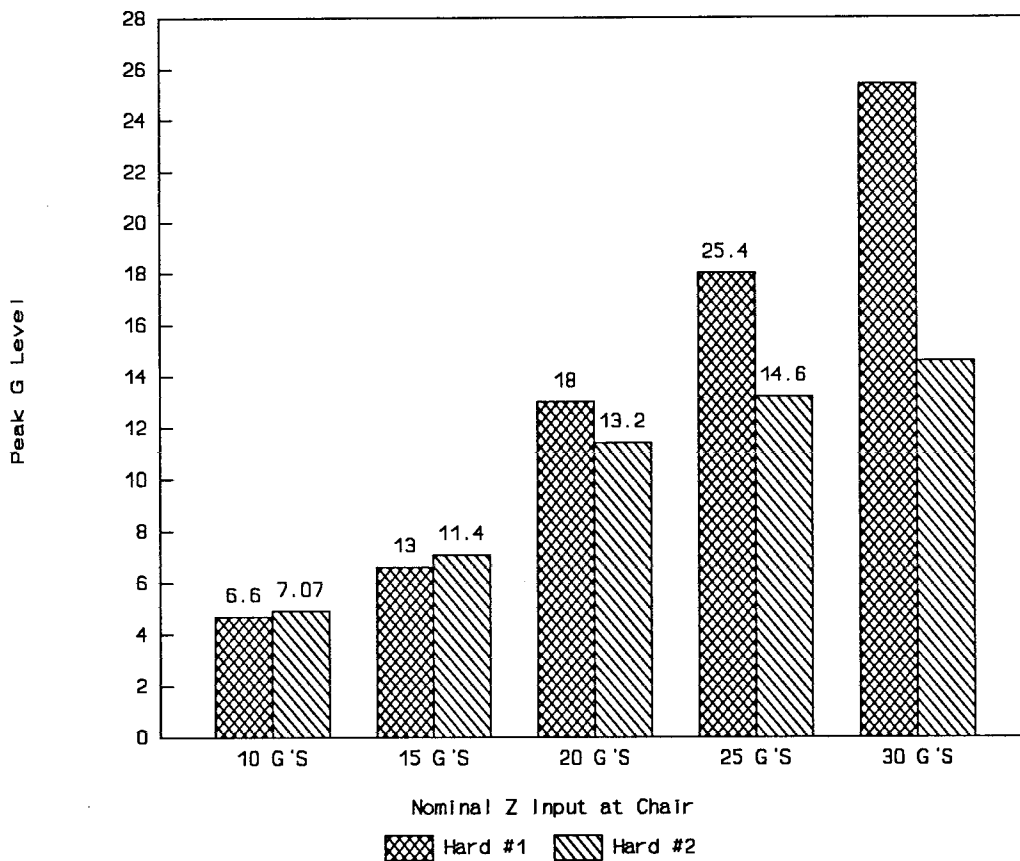


Figure 10. Hard Seat Pelvis X Comparison.

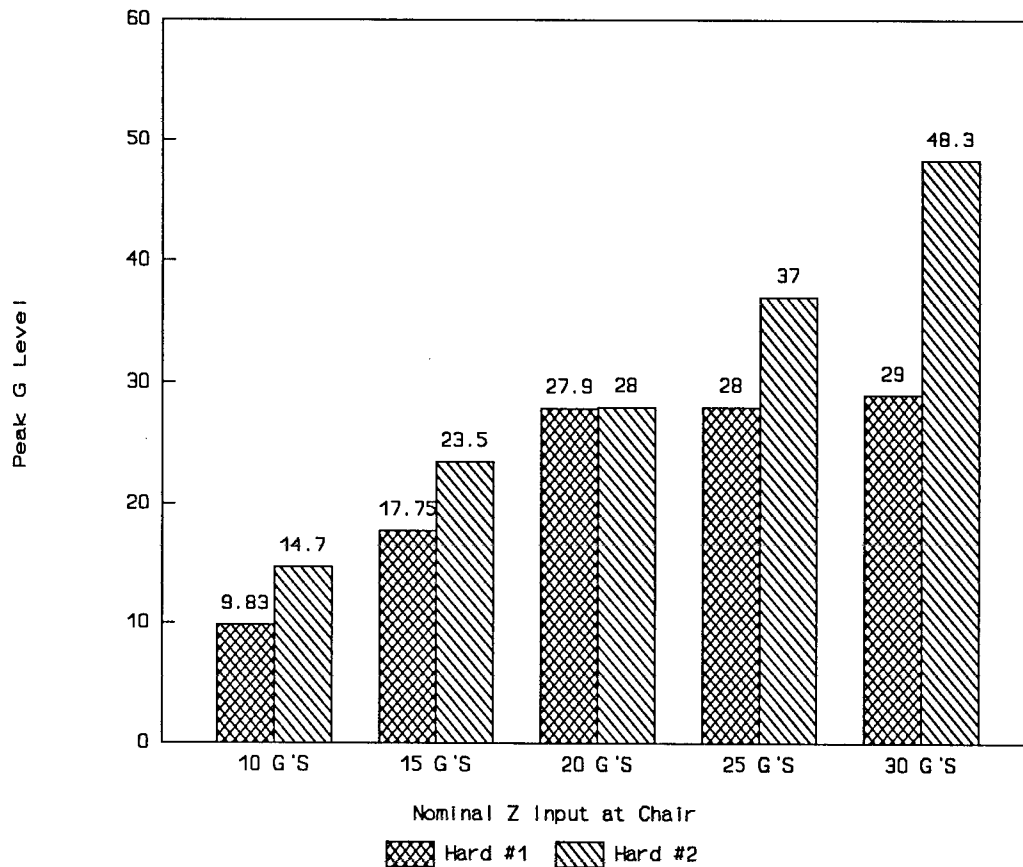


Figure 11. Hard Seat Pelvis Z Comparison.

3.3 MANIKIN RESPONSE

The primary dynamic response components of the manikin to +Z shock pulses are linear accelerations along the Z-axis at all three measurement stations, head rotation about the Y-axis, and head translation along the X-axis. Figures 12 and 13 are sample time history plots of shock propagation through the dummy's pelvis and T-1 for a nominal 25 G test utilizing the SPOC, and the hard seat respectively. The head responses as a function of time are shown in the Appendix. Figures 14 and 15 summarize the hard vs soft seat Z-axis peak acceleration propagation for two input levels of nominally 10 and 25 Gs. Figures 16 and 17 summarize head X-axis translation as well as head rotation about the Y-axis for two test replications at 10 and 25 Gs respectively.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

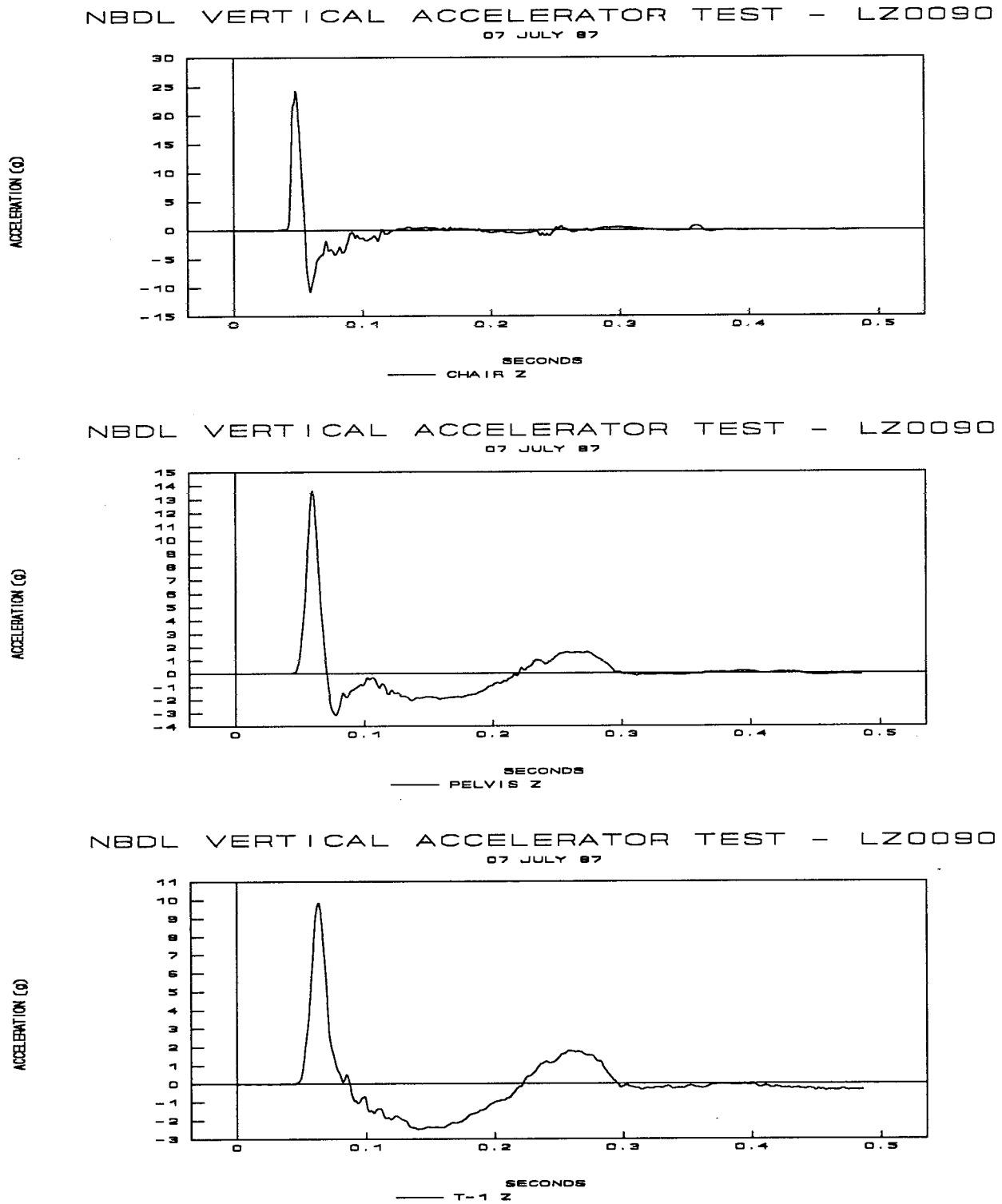


Figure 12. Shock Propagation through Pelvis and T-1 SPOC.

NAVAL BIODYNAMICS LABORATORY REPORT

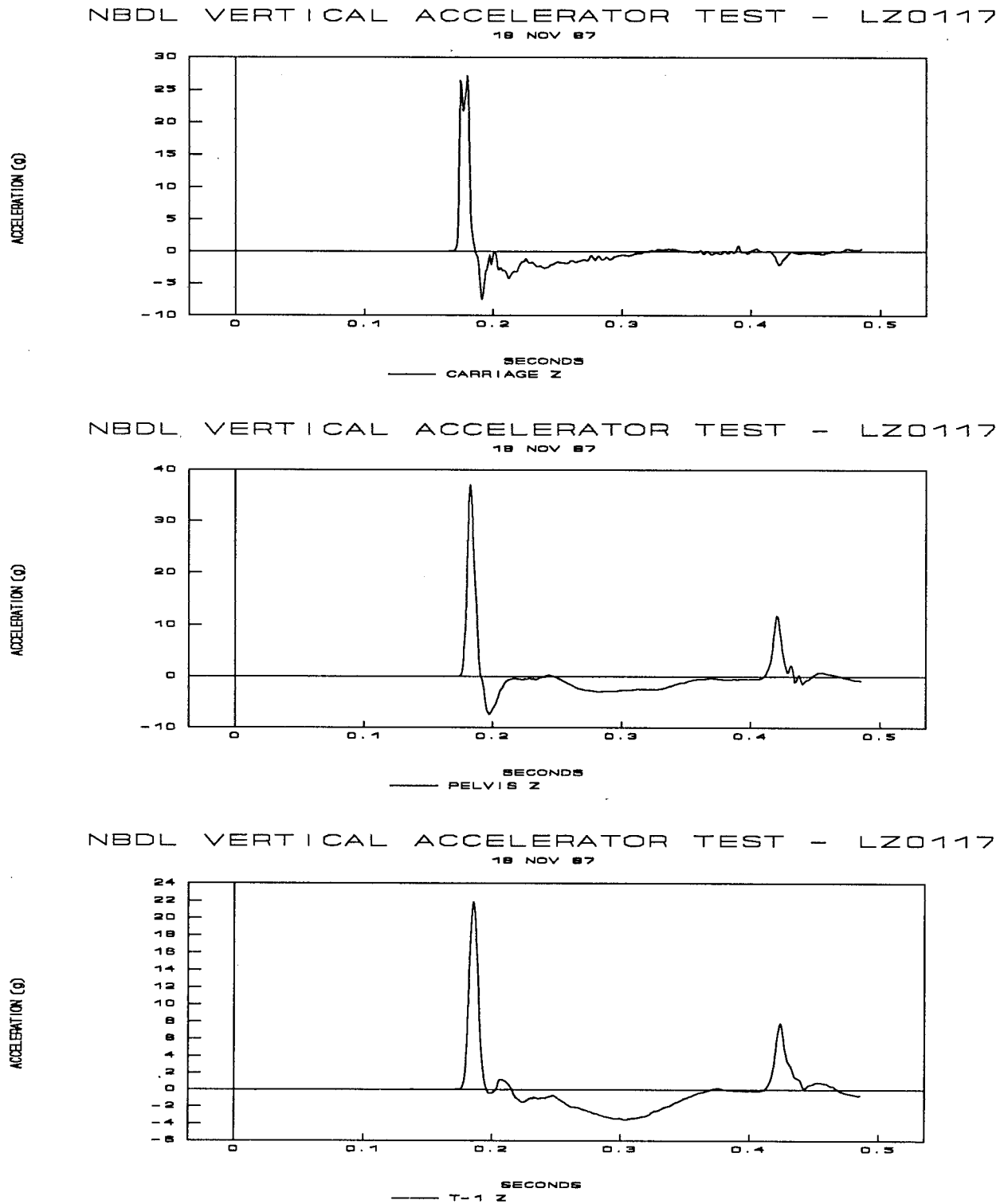


Figure 13. Shock Propagation through Pelvis and T-1 Hard Seat.

Hybrid III Dummy Response to +G_Z Simulated Ship Shock

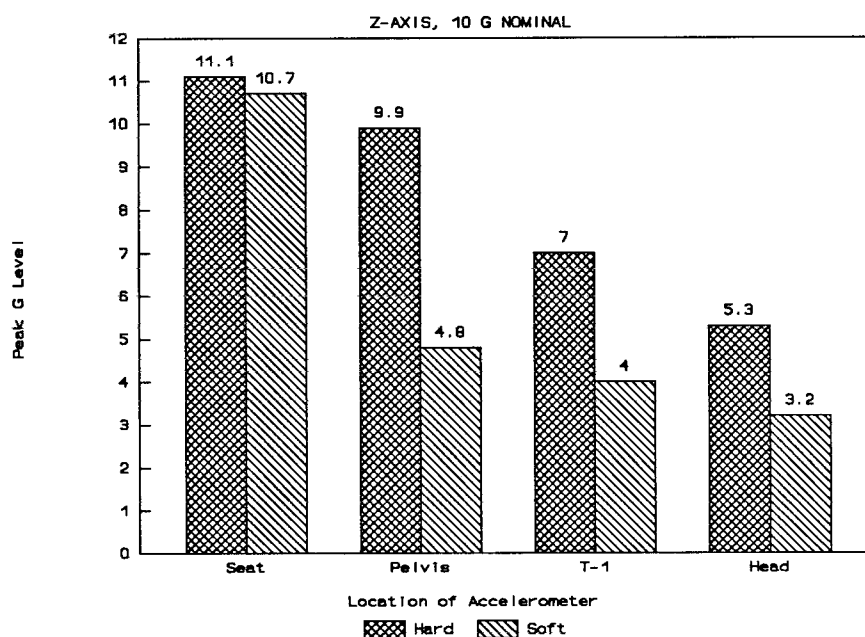


Figure 14. Hard vs. Soft Seat Comparison.

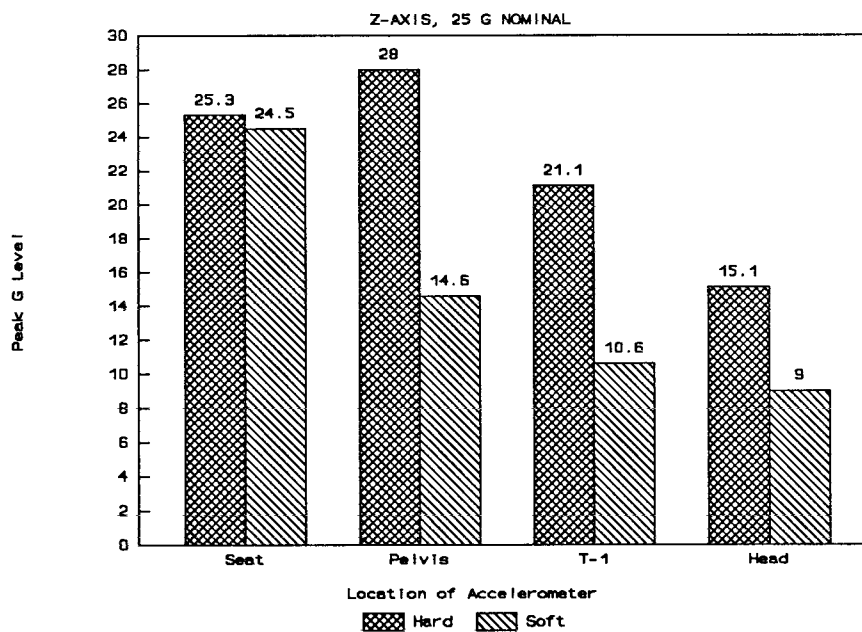


Figure 15. Hard vs. Soft Seat Comparison.

NAVAL BIODYNAMICS LABORATORY REPORT

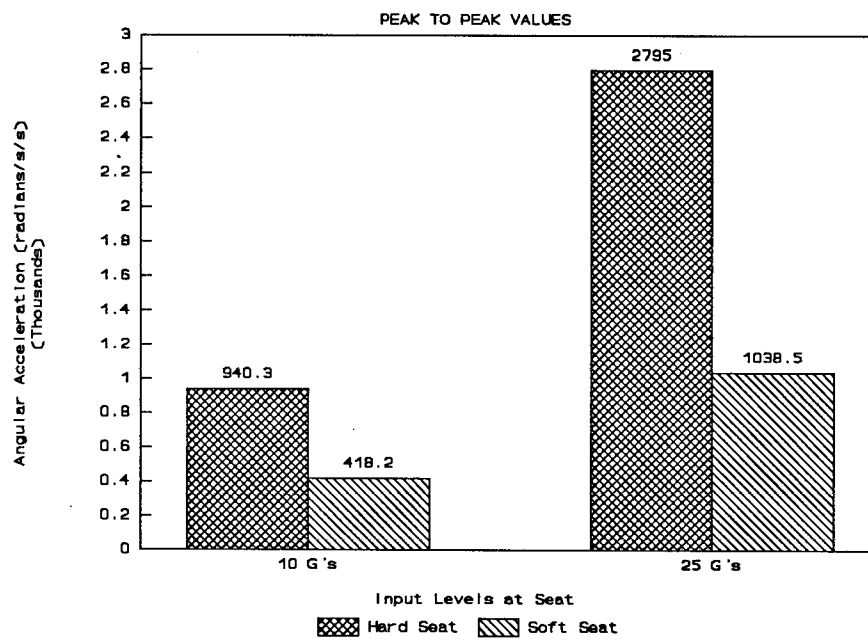


Figure 16. Head @Y Angular Acceleration.

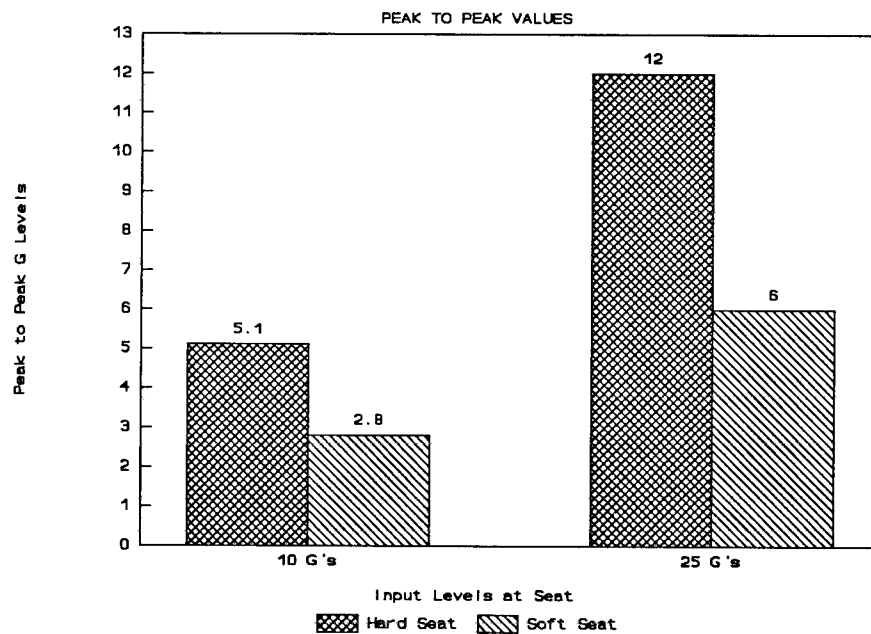


Figure 17. Head X Linear Acceleration.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

In comparing the hard vs soft seat responses of the manikin, two things are evident. First the hard seat pelvic response of the manikin to the higher level inputs exhibit what appears to be a dynamic overshoot, i.e., the pelvis peak Z acceleration exceeds the input acceleration. Secondly, the soft seat does provide considerable shock attenuation. The dynamic overshoot phenomenon begins to manifest itself at approximately 15 Gs. The relative attenuation into T-1 and the head appear to be independent of the input acceleration level and the almost two-to-one attenuation afforded by the soft seat also seems to be independent of the input level.

A direct comparison of manikin response to simulated (Vertical Accelerator) and real (CVN-71 Shock Trials) shock inputs was made. These sample time traces are shown in Figures 18 through 21. Figure 18 depicts the input shock pulses; the relatively "noisy" response of the deck accelerometer, as compared to the USS YORKTOWN (CG-48) response (Figure 1), was probably due to its location within the ship. In the CVN-71 trials, the accelerometer was mounted on the deck in the middle of an empty ammunition magazine. As shown in the subsequent plots however, the manikin responds only to the primary pulse. It is evident from Figures 18 through 21 that the manikin's response to simulated shock is quite realistic even though in this shock trial the manikin was standing. Due to ocean bottom characteristics and because the CG-53 responded in an entirely different manner than the CG-48, data from the other trial which featured a seated dummy were not used. The simulated shock pulse more nearly replicated the CVN-71's response.

NAVAL BIODYNAMICS LABORATORY REPORT

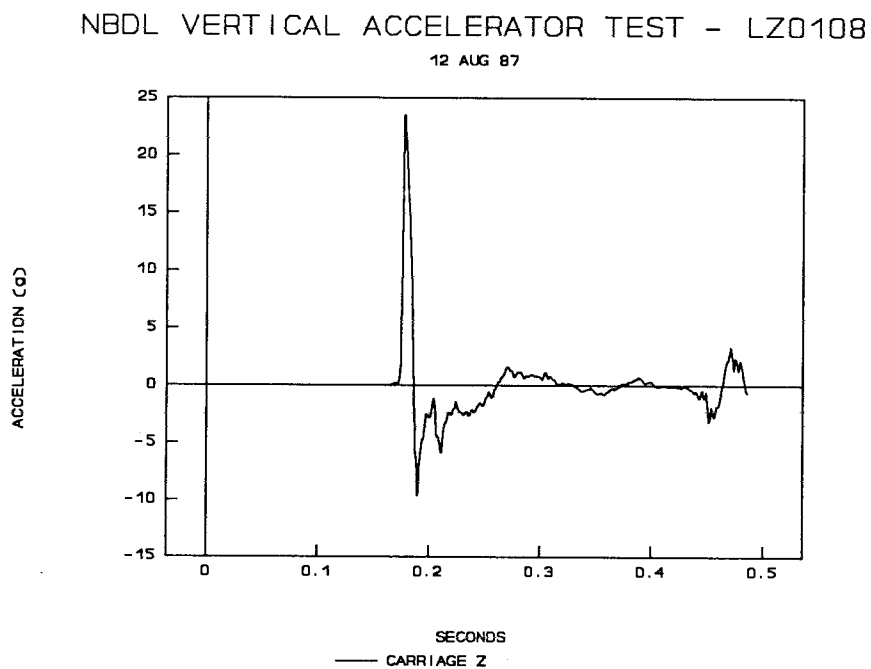
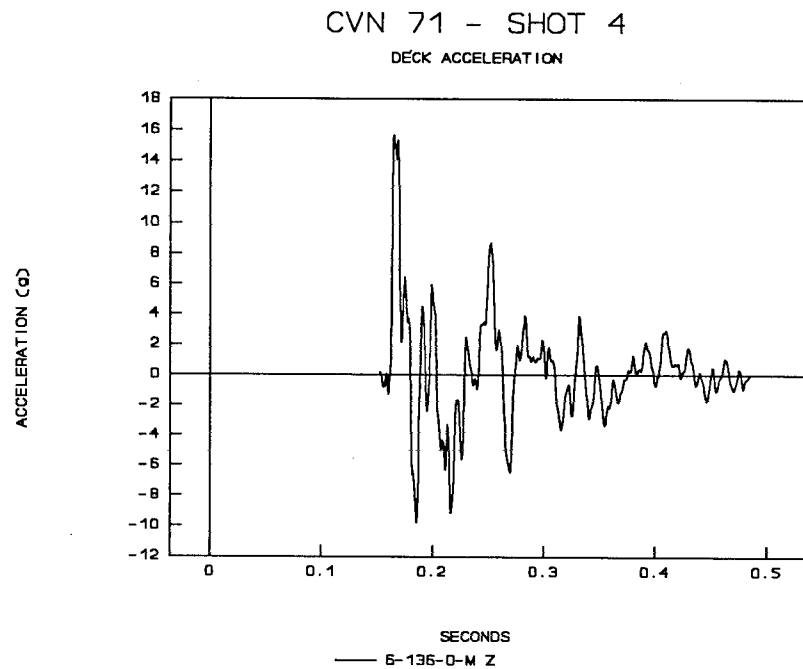


Figure 18. Comparison of Actual and Simulated Shock Pulses.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

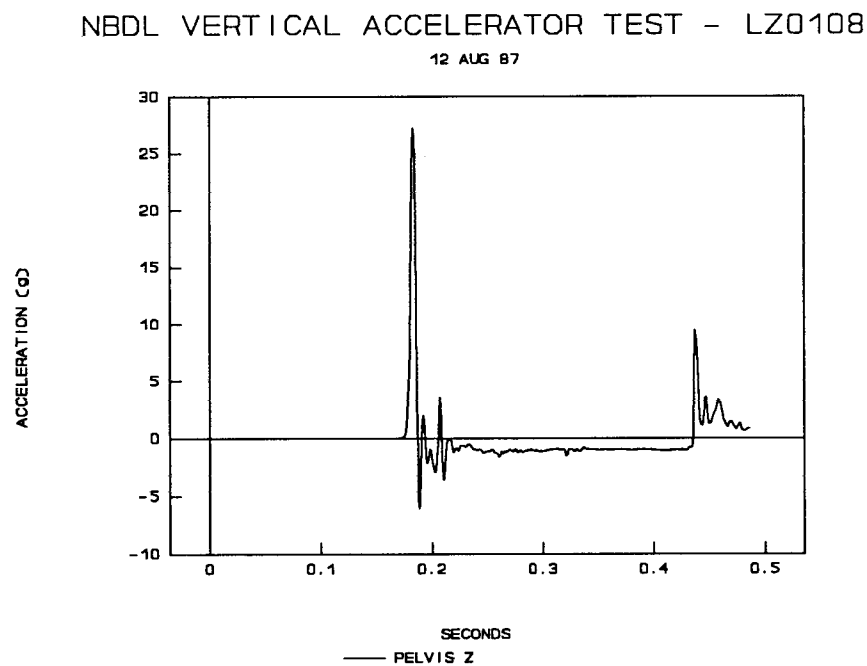
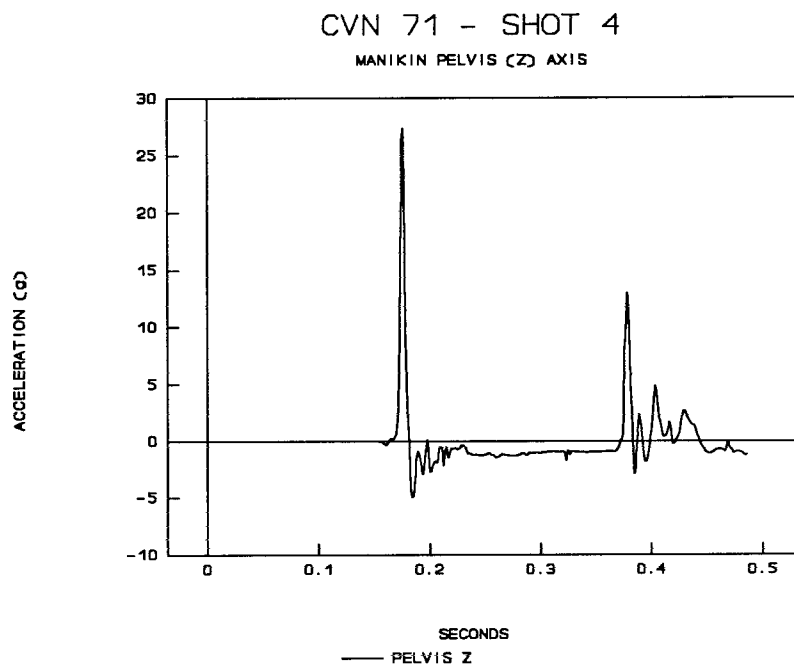


Figure 19. Pelvis Z-axis Response to Actual and Simulated Shock Pulses.

NAVAL BIODYNAMICS LABORATORY REPORT

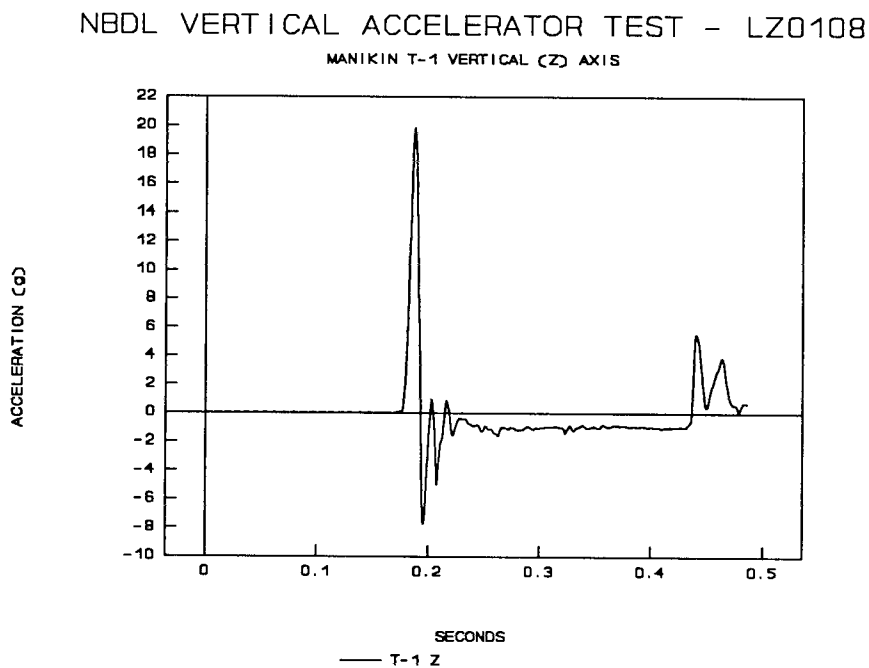
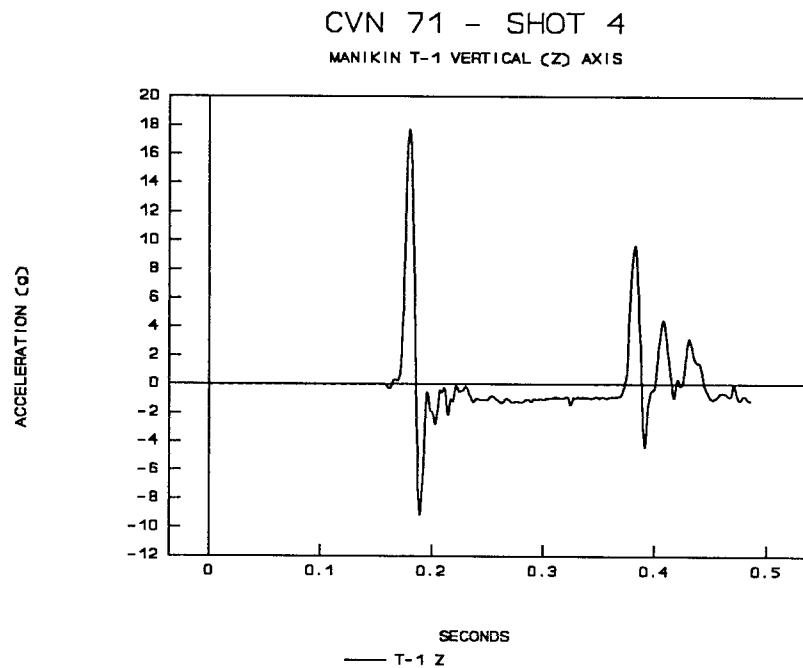


Figure 20. T-1 Z-axis Response to Actual and Simulated Shock Pulses.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

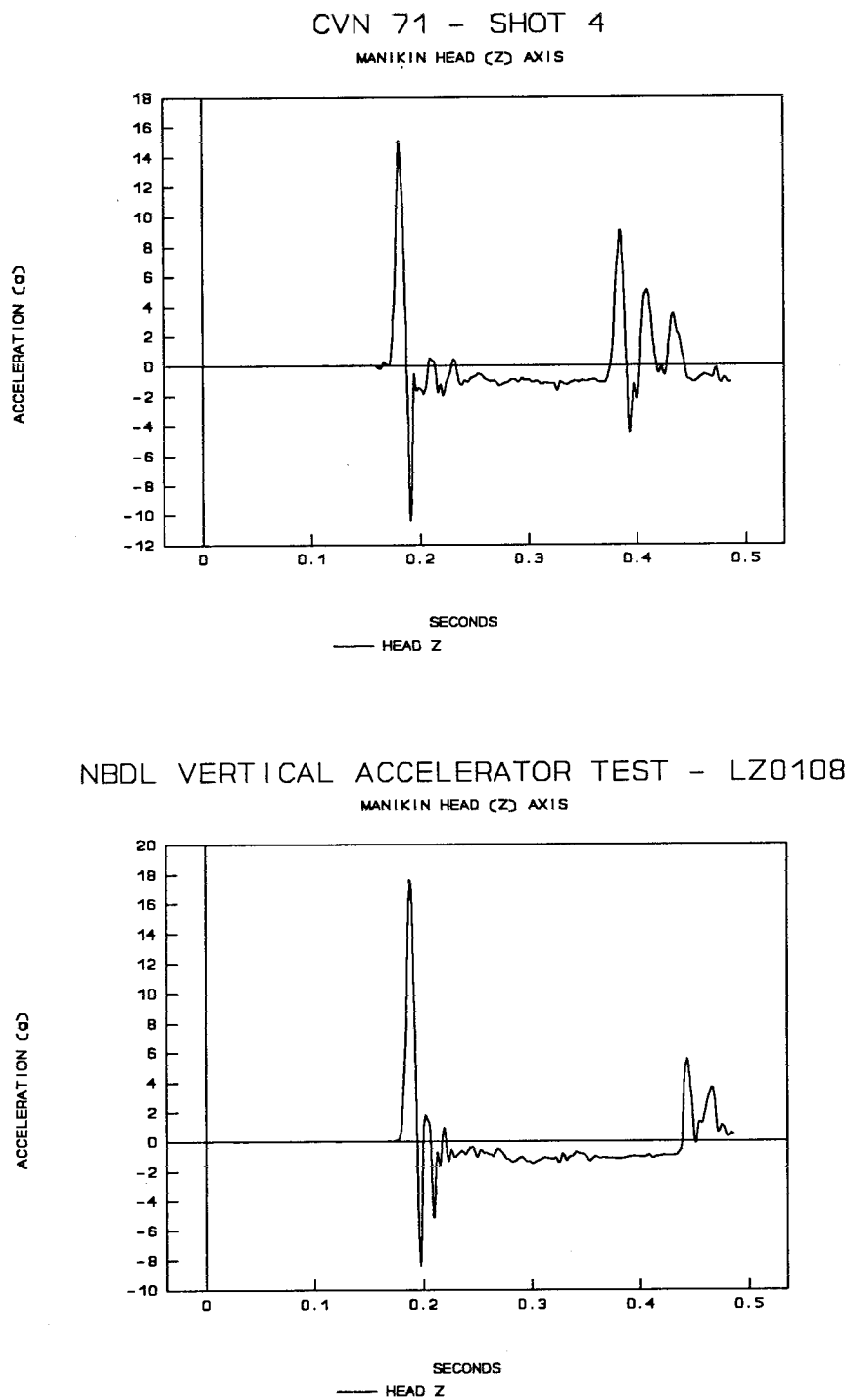


Figure 21. Head Z-axis Response to Actual and Simulated Shock Pulses.

4. SUMMARY

The principal component of impact acceleration during ship shock trials is along the Z-axis. NAVBIODYNLAB's Vertical Accelerator is able to accurately duplicate this shock pulse and can therefore, be used to realistically simulate ship response to underwater explosions. This capability has a number of potential applications.

The instrumentation developed to measure the dynamic response of various body anatomical segments and shock propagation through the body provides reliable and repeatable measurements of the motion.

Seat design can significantly attenuate the shock input into the body. The results presented herein for the SPOC can be generalized to other areas, resulting in a safer environment for ship crews. The shape of the hard surfaces in contact with the body can also materially affect the latter's response to shock.

5. CONCLUDING REMARKS

At the time the tests described herein were conducted, NAVBIODYNLAB's Vertical Accelerator was not man-rated. It was man-rated in 1989 and has since been used for a large number of experiments using human research volunteers. These test subjects are fully instrumented with inertial transducers similar to the ones described herein. Additionally, their motion is tracked in three dimensions with high speed cinematography. This capability could be exploited for performing studies in human response to ship shock at sub-injury levels. The result of these experiments would then yield both safe exposure limits for ship shock, and a database for the development of mathematical models of the response which would allow extrapolation to determine injury thresholds. The cost of such a study would be minuscule compared to the cost of performing a similar study during actual shock trials at sea.

Hybrid III Dummy Response to +G_z Simulated Ship Shock

REFERENCES

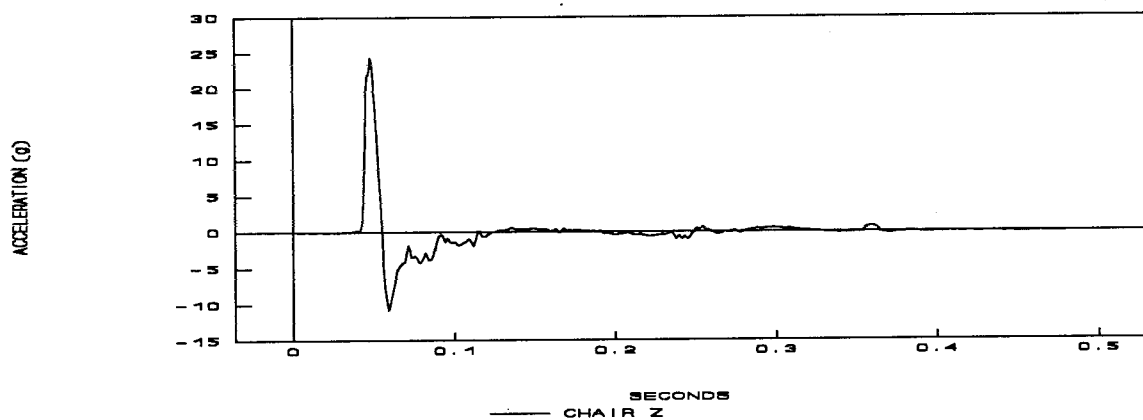
1. Durkovic, R. G., and Hirsch, A. E., Personnel Injuries and Estimated Shock Motions on YMS 368 During a Mine Attack, Report No. C-1318, David Taylor Model Basin, Washington, DC, May 1962.
2. Hirsch, A. E., and Johnson, B., Personnel Casualties Resulting from Underwater Explosive Attacks Against Naval Surface Ships, Report No. C-1582, David Taylor Model Basin, Washington, DC, July 1963.
3. Hirsch, A. E., Man's Response to Shock Motions, Report No. C-1797, David Taylor Model Basin, Washington, DC, January 1964.
4. Hirsch, A. E., Shiabani, S. J., Nguyen, T. T., Willems, G. C., and Muzzy, W. H., III, Response of Seated and Standing Manikins during Shock Trials on USS MOBILE BAY (CG-53) and USS ROOSEVELT (CVN-71), Report No. NBDL-89R005 (NTIS No. AD A212586), Naval Biodynamics Laboratory, New Orleans, LA, May 1989.
5. Muzzy, W. H., III, Seemann, M. R., Willems, G. C., Lustick, L. S., and Bittner, A. C., Jr., "The Effects of Mass Distribution Parameters on Head/Neck Dynamic Response." *Thirtieth Annual Stapp Car Crash Conference Proceedings*, Society of Automotive Engineers, Warrendale, PA, pp. 167-183, 1986.
6. Seemann, M. R., Muzzy, W. H., III, and Lustick, L. S., "Comparison of Hybrid III Head and Neck Dynamic Response." *Thirtieth Annual Stapp Car Crash Conference Proceedings*, Society of Automotive Engineers, Warrendale, PA., pp. 291-311, 1986.

APPENDIX A

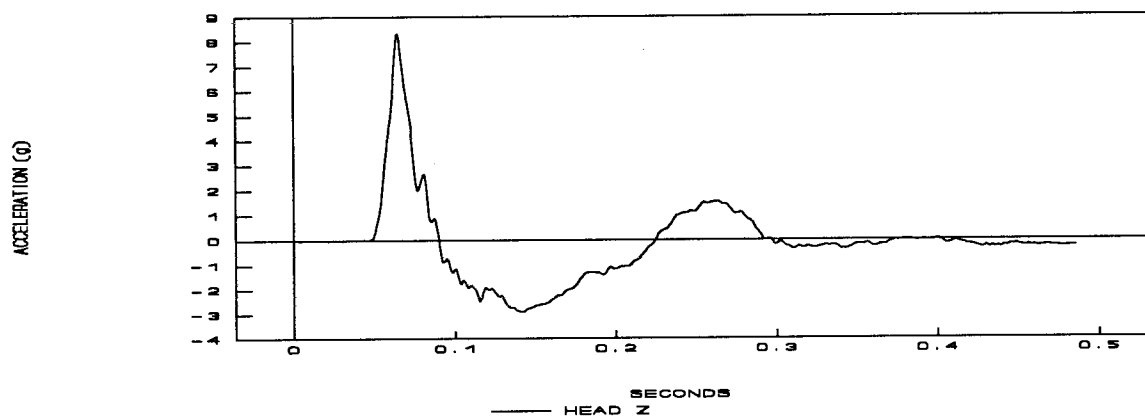
MANIKIN'S HEAD RESPONSES TO SIMULATED SHIP SHOCK AS A FUNCTION OF TIME

Hybrid III Dummy Response to +G_Z Simulated Ship Shock

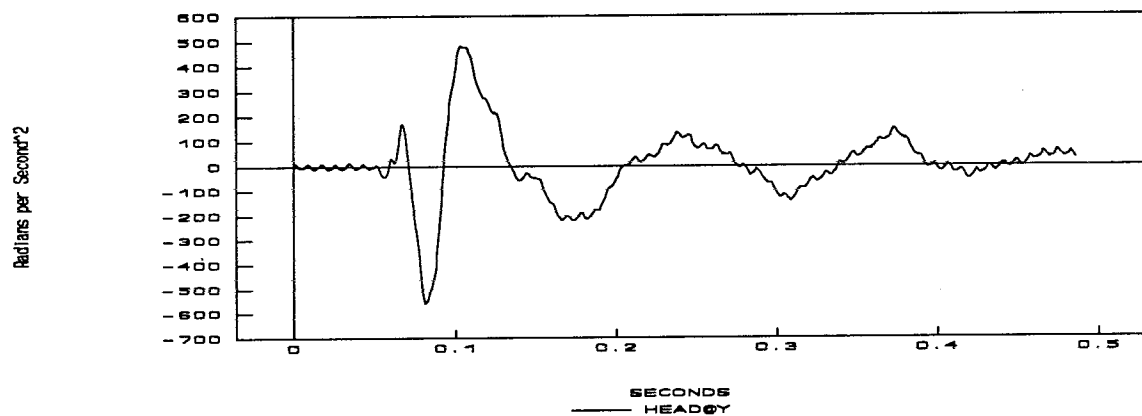
NBDL VERTICAL ACCELERATOR TEST - LZ0090
07 JULY 87



NBDL VERTICAL ACCELERATOR TEST - LZ0090
07 JULY 87



NBDL VERTICAL ACCELERATOR TEST - LZ0090
07 JULY 87

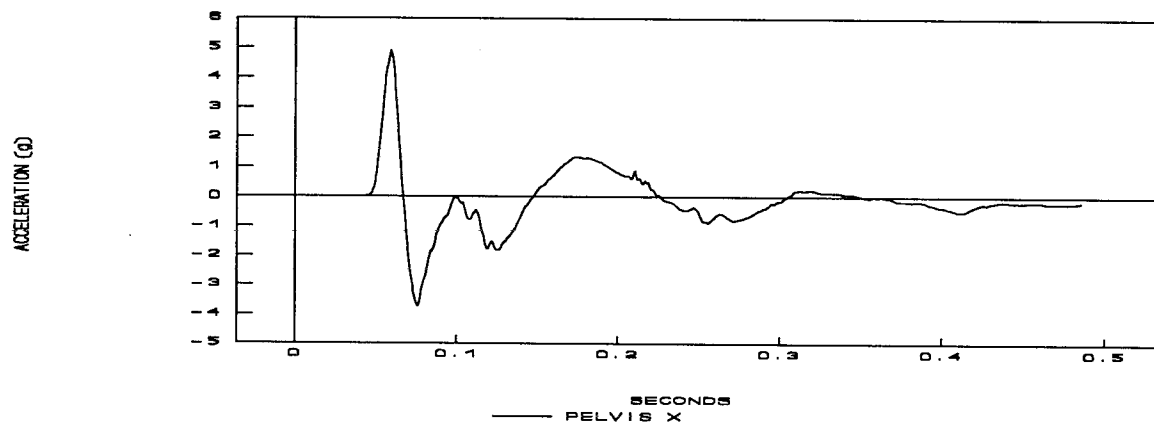


Head Linear and Angular Response to Shock - SPOC.

NAVAL BIODYNAMICS LABORATORY REPORT

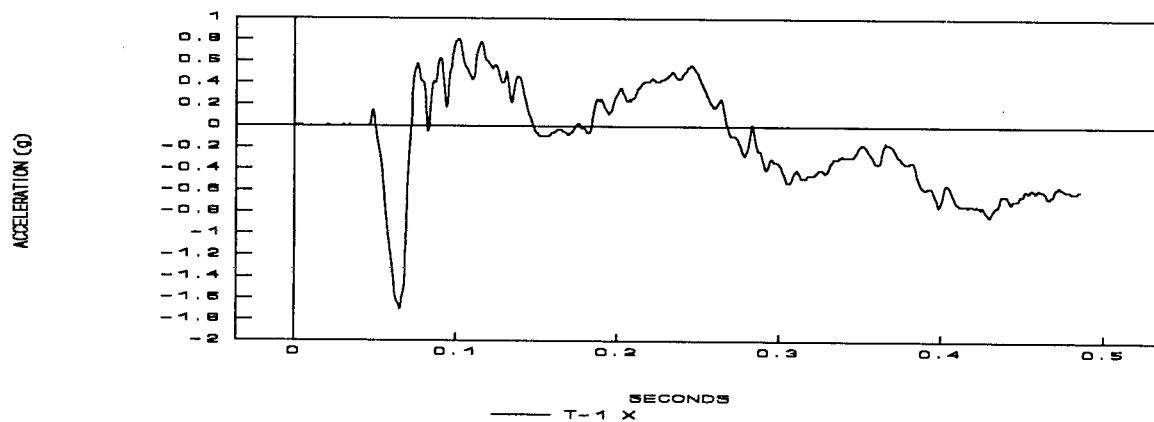
NBDL VERTICAL ACCELERATOR TEST - LZ0090

07 JULY 87



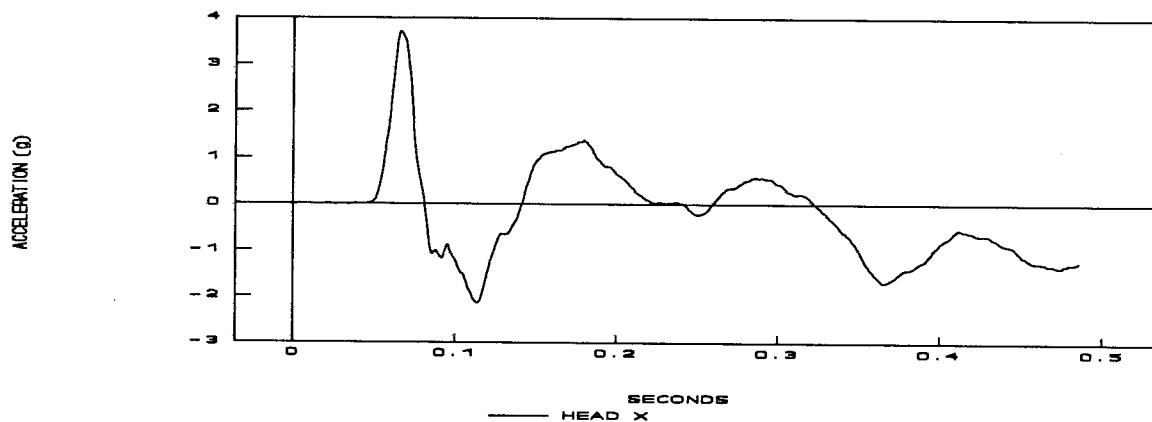
NBDL VERTICAL ACCELERATOR TEST - LZ0090

07 JULY 87



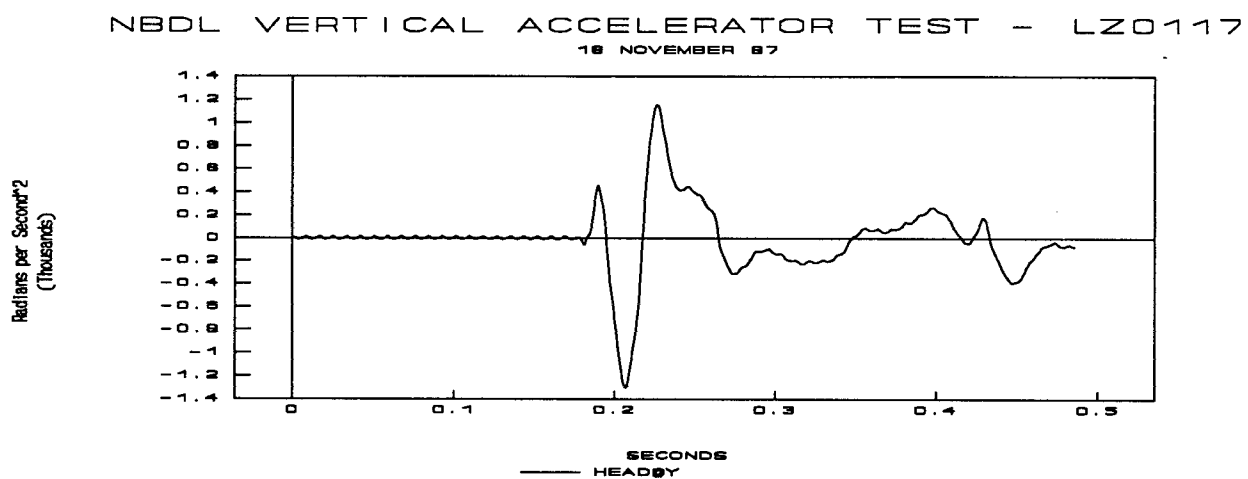
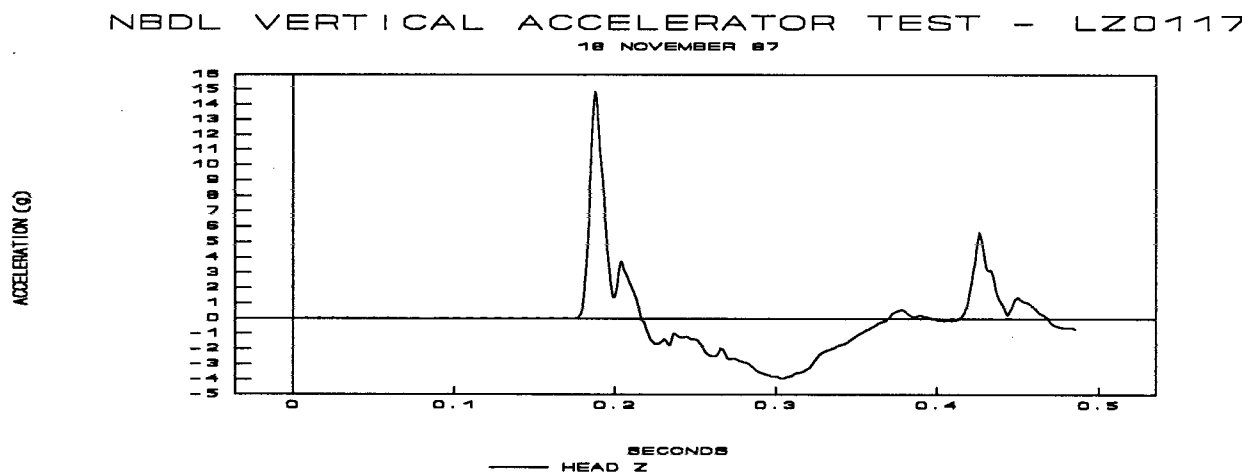
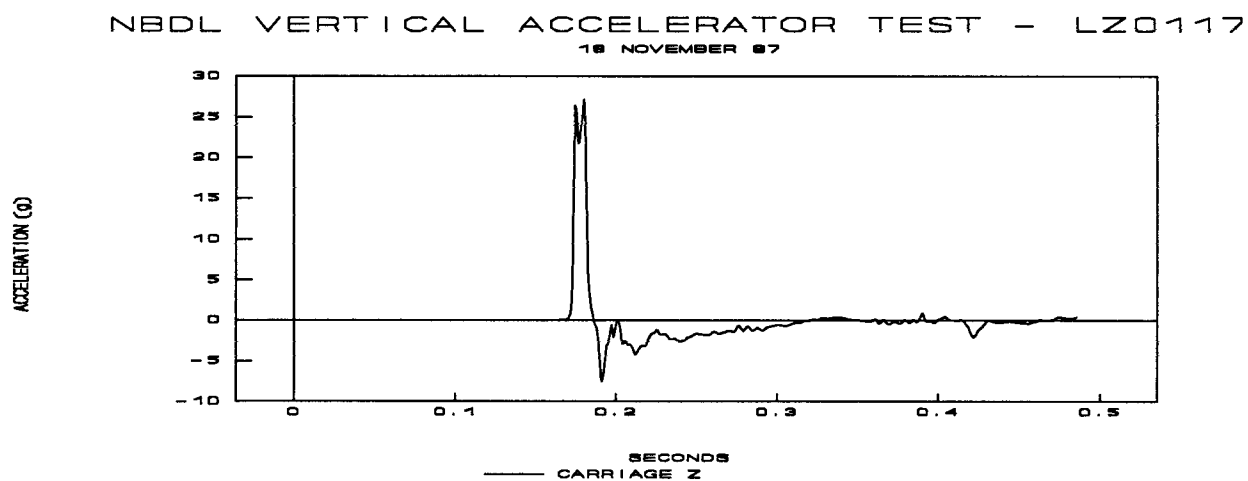
NBDL VERTICAL ACCELERATOR TEST - LZ0090

07 JULY 87



Dummy X-axis Response to Shock - SPOC.

Hybrid III Dummy Response to +G_Z Simulated Ship Shock

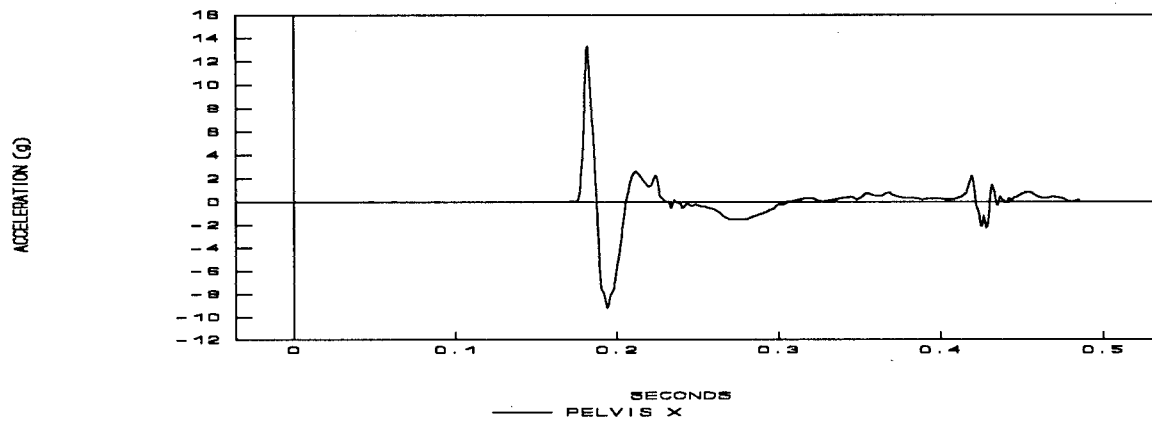


Head Linear and Angular Response to Shock - Hard Seat.

NAVAL BIODYNAMICS LABORATORY REPORT

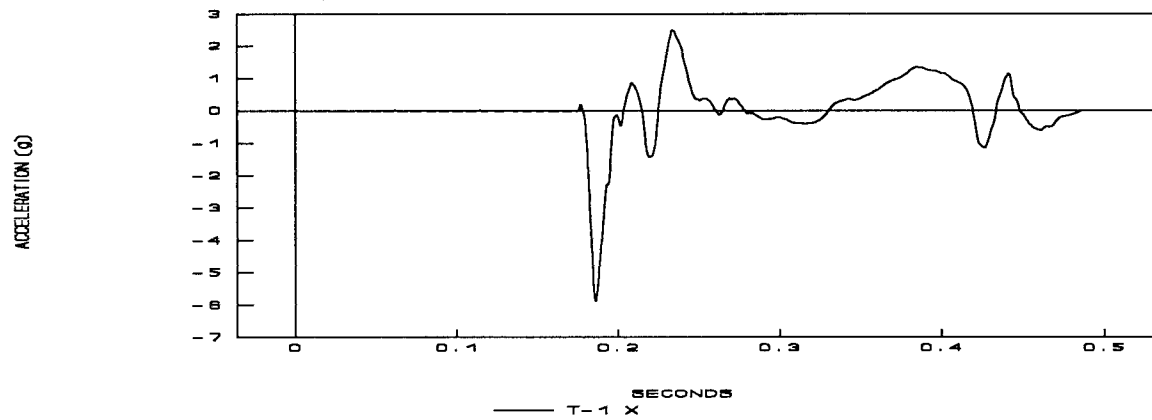
NBDL VERTICAL ACCELERATOR TEST - LZ0117

18 NOVEMBER 87



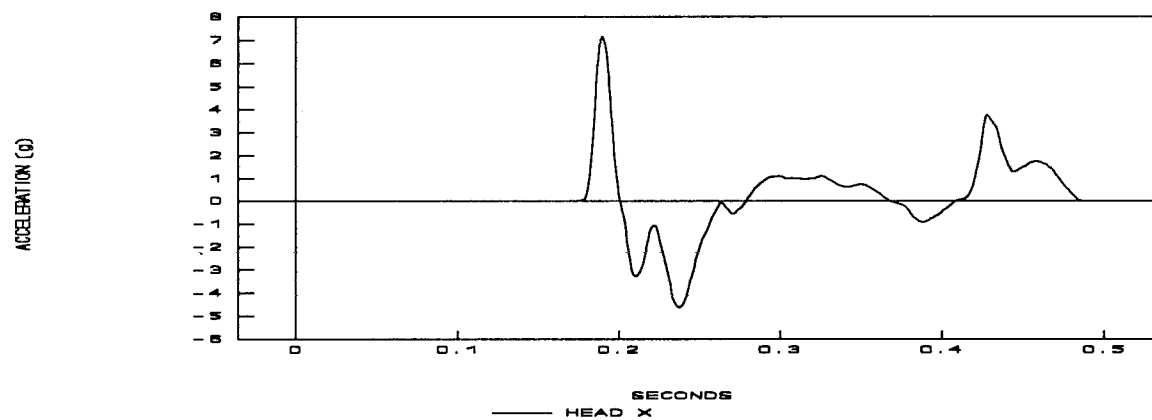
NBDL VERTICAL ACCELERATOR TEST - LZ0117

18 NOVEMBER 87



NBDL VERTICAL ACCELERATOR TEST - LZ0117

18 NOVEMBER 87



Dummy X-axis Response to Shock - Hard Seat.

A-4

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE November 1991		3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE Dynamic Response of the Hybrid III Dummy to +G _z Simulated Ship Shock -- Cushioned vs Hard Seats			5. FUNDING NUMBERS 63216N.M0097.001	
6. AUTHOR(S) G. Willems, W. Muzzy, III, D. Knouse, and F. Gilreath				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Biodynamics Laboratory P. O. Box 29407 New Orleans, LA 70189-0407			8. PERFORMING ORGANIZATION REPORT NUMBER NBDL-91R002	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Medical Research and Development Command National Naval Medical Center Building 1, Tower 12 Bethesda, MD 20889-5044			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The response of an operator to simulated ship shock was evaluated for a subject seated on the Special Purpose Operator's Chair (SPOC). An instrumented Hybrid III manikin was vertically impacted at levels from 3 to 30 Gs on the Naval Biodynamics Laboratory's (NAVBIODYNLAB) Vertical Accelerator, adjusted to simulate ship Z-axis response to underwater explosions; the 30 G level exceeds the maximum values observed in several ship shock trials. The experiments were conducted using both the SPOC and two versions of a hard-bottomed seat in order to evaluate the shock attenuating capability of the SPOC. The evaluation of the capability of the Vertical Accelerator to accurately simulate ship shock and to produce repeatable results was also a goal of this program and was successfully achieved.				
14. SUBJECT TERMS Evaluate capability of Vertical Accelerator; stimulate ship shock; produce repeatable results.			15. NUMBER OF PAGES 32	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	